# Effect of a Dynamic Keyboard and Word Prediction Systems on Text Input Speed in Patients with Functional Tetraplegia

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|---|---|
| Keywords: | Assistive technology, Computer, Dynamic keyboard, Learning, Satisfaction, Text input speed, Quadriplegia, Self help devices, Virtual Keyboard, Word prediction |

17/12/2012

Dear Sir/Madam,

Please find attached the revised version of our manuscript entitled: "**Effect of a Dynamic Keyboard and Word Prediction System on Text Input Speed in Participants with Tetraplegia**"

We have replied to all the reviewers' comments and have substantially modified the text. We hope that you and the reviewers now find the manuscript suitable for publication in Journal of Rehabilitation Research and Development.

Yours sincerely,

Samuel POUPLIN, Johanna ROBERTSON, Djamel BENSMAIL

**TITLE : Effect of a Dynamic Keyboard and Word Prediction Systems on Text Input Speed in Participants with Functional Tetraplegia**

**SHORT TITLE: Effect of Prediction System on Text Input Speed.**

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**Statement of responsibility :**

Samuel POUPLIN, participated in the conception and design of the protocol, analysis and interpretation of data and drafting the article. Justine BOUTEILLE participated in the conception and design of the protocol. ,Johanna ROBERTSON participated in the analysis and interpretation of data and drafting the article. Jean-Yves ANTOINE, programmed Sybille software and helped to draft the article, Antoine BLANCHET, Jean Loup KAHLOUN, and Philippe VOLLE programmed CVK software. Frédéric LOFASO helped to draft the article, Djamel BENSMAIL participated in the analysis and interpretation of data and drafting the article.

## ABSTRACT

**Purpose:** Information technology plays a large role in both the social and the professional lives of individuals. Text input is often slow with assistive devices which provide computer access to disabled people. The aim of this study was to evaluate the effect of a dynamic on-screen keyboard (Custom Virtual Keyboard, CVK) and a word prediction system (Sybille) on text input speed in participants with functional tetraplegia.

**Method:** 10 participants tested four modes at home (static on-screen keyboard with and without word prediction and dynamic on-screen keyboard with and without word prediction) for 1 month before choosing one mode and using it for another month.

**Results:** The dynamic keyboard reduced text input speed compared with the standard keyboard and the addition of word prediction had no effect on text input speed.

**Conclusions:** This study raises many questions regarding the indications for specific assistive devices and software, as well as the optimal ergonomic design of dynamic keyboards and the number and position of words that should be predicted. The development of the CVK is continuing, and future studies will aim to address these questions in larger numbers of participants.

**KEY WORDS:** Assistive technology. Computer. Dynamic Keyboard. Learning. Satisfaction. Quadriplegia. Self-help devices. Text Input Speed. Virtual Keyboard. Word Prediction System.

**ABREVIATIONS**

CVK : Custom Virtual Keyboard



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**Introduction**

Computers now play an important role in the lives of most individuals. They are used for recreational purposes (e.g. multimedia and games), work, and communication (internet, email, instant messages) (Bigot [1]). Access to the computer is crucial for disabled people and may improve their quality of life (Boonzaier [2]). The use of computers can facilitate mainstreaming at school, for example, and the Internet may provide a valuable means of communication (Picard [3]) (ANLH [4]). However, the use of computers requires a certain degree of motor ability. People with motor disabilities frequently experience difficulties in using pointing input systems (mouse to displace an on-screen cursor) and also with inputting text (via a keyboard). Many solutions exist to facilitate computer access, depending on the patient's specific impairments and the purpose for which the computer is used (Devries [5]), (Chen [6]), (Lopresti [7]), (Pouplin [8]). The most common solution relies on the use of a virtual keyboard which is directly displayed on the computer screen. The selection of the desired key on the virtual keyboard can be handled by a large variety of input devices, from a microgravity mouse to single switch devices supplemented by a process of dynamic scanning of the keyboard.

Although such assistive devices render computers accessible to disabled people, the actual inputting of text can be very slow. Over the past few years, attempts have been made to develop systems to improve text input speed.

One method is to optimise the layout of the keys on the keyboard (Dvorak [9]). Several studies have shown that altering the layout of static onscreen keyboards, based or not on bigrams of words reduces the number of movements necessary when using pointing devices or the number of selections by switches (MacKenzie,[10]) (Raynal, [11]) (Lesher, [12]) (Schadle, [13]). In all cases, the effect on text input speed remains limited.

Ambiguous and dynamic keyboards have been developed to increase text input speed. Ambiguous keyboards combine several letters on the same key, for example as on mobile telephones (Kushler, [14]) (Lesher, [15]). Dynamic keyboards alter the layout of the keyboard at each keypress so that the characters most likely to follow are positioned around the one which has just been typed (Ward, [16]) (Heckathorne [17]). Both these keyboards have been shown to reduce the number of key selections necessary or the latency between two selections for people using scanning devices (Harbush, [18]) and the displacement of the cursor for people using pointing devices (Merlin [19]). However, very few studies have evaluated the effect of such keyboards on text input speed in participants with motor disability over a long duration.

Another method to increase text input speed is to display words which are predicted from the letters previously typed. Word prediction reduces the number of necessary key strokes by avoiding having to type the whole word.  Higginbotham found keystroke savings of 40-50% (Higginbotham [20]) in healthy subjects using word prediction in 5 different types of communication software for disabled people, available on the market, however the effect on text input speed is uncertain and results in the literature are inconclusive (Koester [21] (Anson, [22]) (Koester [23]) (Koester [24]).

The aim of this study was to carry out a preliminary evaluation of a dynamic on-screen keyboard and a word prediction system (Custom Virtual Keyboard, CVK) on text input speed in participants with functional tetraplegia, using the systems over a period of 2 months at home. The Custom Virtual Keyboard (CVK) was developed by our team and is available free of charge (Figure n°1).

We hypothesized that both word prediction and the dynamic keyboard would increase text input speed and thus the combination of both systems would further increase text input speed.

## Method

### Participants

Participants with functional tetraplegia followed-up at the Physical Medicine and Rehabilitation department of the Raymond Poincaré Teaching Hospital (Garches, France) between 2005 and 2010 were contacted by telephone to determine whether they fulfilled the inclusion criteria and wished to participate. Participants were included if they were over 18 years old, had functional tetraplegia (e.g. due to locked-in syndrome, myopathy, or cervical spinal cord injury), regularly used an on-screen static AZERTY keyboard based on a PC computer with Windows (the only operating system that can accommodate the CVK at present) and who were not regular users of dynamic keyboards or word prediction. Participants had home access to the internet, and lived in or near Paris, France. Participants were excluded if they had cognitive, linguistic or visual impairments preventing the use of a computer.



### Material

This study was carried on the CVK (Custom Virtual Keyboard), which was developed by our team and is available as open source software (Figure n°1).


Figure 1: CVK Onscreen Keyboard

Text input using the CVK can be achieved using pointing devices or, for patients with too little motor capacity to use a pointing device, via automatic scanning. When a pointing device is used, the user positions the cursor using a pointing device over the desired virtual key and then validates the choice. This type of mode fits, for instance, the needs of people with functional tetraplegia who use a head pointing device. For people who can only control their physical environment by means of a single switch, an automatic process enables the cursor to successively scan all the relevant positions of the screen. When the intended key is reached by the cursor, the user validates that key using a switch. This form of text input is, however, very slow. Two types of scanning mode were used in this study: row-column and linear. The row-column mode significantly reduces the number of cursor shifts needed to reach the intended key but requires two keystrokes (line and column) to select each item, thus increasing the physical effort of the user. Linear scanning requires only a single keystroke since all the keys are systematically scanned successively. When used with a static AZERTY keyboard, text input speed is therefore dramatically reduced if the intended key is situated at the end of the keyboard.

Two types of keyboard exist within the CVK: a standard onscreen static AZERTY keyboard and a dynamic onscreen keyboard. The dynamic mode is based on the Sibylle AAC system (Wandmacher [25]) and consists of an automatic rearrangement of the characters on the keyboard after each selection such that the characters that are most likely to be typed next are displayed next to the character which has just been typed, taking into account the previously selected letters. This rearrangement is achieved by the stochastic letter prediction module of Sibylle, which was trained on a large corpus of around 100 millions words. Figure n°2 illustrates this dynamic modification of the keyboard display (English version of Sibylle) when the user tries to write the word *three*. At first, the letters are set in the following order :

*t*, *a*, *i*, *s*, *o*,. The letter *t* is the most frequent letter that begins a word in the trained corpus. When, the user selects the letter *t*, the keyboard is automatically rearranged in the following new order : *h*, *o*, *r*, *e*, *a* … Here, the letter *h* is proposed first since it is the most likely to occur after the letter *t*. In other words, the conditional probability P( $w_i$ | $w_{i-1} = t$) is maximum with $w_i = h$. The letter prediction module of the CVK is based on a 5-gram language model P($w_i$ | $w_{i-1}$ , | $w_{i-2}$ , | $w_{i-3}$ , | $w_{i-4}$), which means that the system considers the last four selected letters for the reorganisation of the keyboard layout.

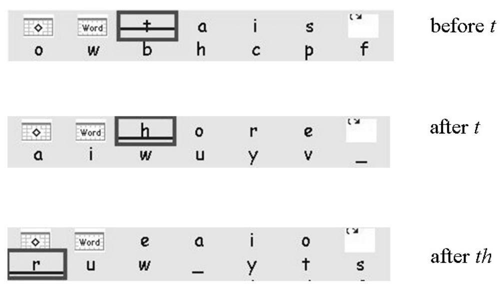


Figure 2 : Reorganization of the dynamic letter sub-keypad (English version of Sibylle)

Theoretically, this dynamic keyboard should speed up the access time to the intended key and thus increase text input speed. As noted in introduction, text input speed can also be increased by means of word prediction, in order to reduce the number of keystrokes required.

The CVK (figure n°1) includes a word prediction module which is based on SibySem, a context-sensitive prediction module which has been shown to reach state-of-the-art performances in French, English and German (Wandmacher [26]). This module is not based on a simple dictionary like standard commercial systems. It is based on a language model which considers the last two words already typed as well as the semantic context of the message. New words are learned dynamically by the system as input continues. Moreover, the system gradually learns the language style of the user. This prediction system is innovative in that word prediction is based on the lexical meaning of the sentence. This characteristic allows the prediction to adjust dynamically to the current topic of interest. Experiments with participants have shown that the word prediction systems can achieve about 60% Keystroke Savings (Wandmacher [26]) when five predicted words are displayed at a time.

The SibySem module provides a list of six - seven predicted words displayed on the screen. The prediction list is displayed horizontally at the top of the virtual keyboard in figure 1 (*bien*, *beaucoup*, *bon*…), and vertically on the left of the keyboard in figure 3.


*Figure 3: CVK dynamic on-screen keyboard with word prediction list on the left*

## Text input modes

In this study, four different modes of the CVK software were compared:

- static on-screen keyboard
- static on-screen keyboard with word prediction
- dynamic on-screen keyboard
- dynamic on-screen keyboard with word prediction.

The static mode consisted of a virtual keyboard with the standard AZERTY layout. The static+word prediction mode consisted of this virtual AZERTY keyboard coupled with the

Sybille word prediction system. The word prediction display was located at the top of the onscreen keyboard and presented seven words (Figure n°1). The scanning system integrated within the static keyboard was row-column. The dynamic mode consisted of a virtual keyboard whose layout changed after each character input to display the characters most likely to be selected next. In the dynamic+word prediction mode, Sybille was used in addition to the dynamic keyboard. The word prediction display was located to the left of the dynamic keyboard and presented five words (Figure n°3). The scanning system integrated within the dynamic keyboard was linear.

**Study design**

This was a pilot study for which ethical approval was not necessary according to French law, since it was an evaluation of usual practice.

The study was carried out over 2 months. The CVK was downloaded on each participant's computer. The participants used their usual interfaces (e.g. trackball, switch, mouse, joystick, or head-controlled device). Specific software was coupled with the CVK to record quantitative data such as software use in hours per day and number of characters typed.

An experienced occupational therapist spent 1 hour with each participant to explain the function of the four study modes. The rationale behind word prediction and dynamic keyboard was explained but subjects were not given specific guidelines or strategies regarding their use. During the first month, the participants tested the four CVK modes.

The modes opened randomly with each CVK session. However, the participants could close the currently opened mode, thus obtaining access to another mode, and could therefore completely avoid the use of one or more modes should they wish to. This choice was made was because we felt it was unfair to limit the participants to use of a mode which he/she may find restrictive.  We were conscious that times of use during the studywere therefore likely not to be equal.

At the end of the first month, the occupational therapist (SP) returned to the participant's home to carry out the assessment. The participant then chose the mode he or she preferred and used it for the next month.

**Assessment**

Three evaluation sessions were carried out: one at baseline (D0), the second at the end of the first month (D30), and the third at the end of the second month (D60) (Figure n°4).

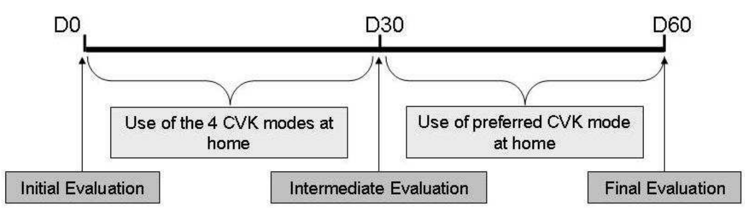


*Figure 4 : The three evaluations*

For each of the 3 assessments (D0, D30, D60), all the modes of CVK were evaluated in a random order. During the evaluation sessions, input speed during a copying task was evaluated using a 400-word text that the participant was asked to type in less than 10 minutes. Participants were instructed to use the word prediction and the dynamic keyboard as desired, i.e. no instructions regarding strategies of use were given. Four texts of similar complexity were used, drawn from national newspapers with an average word length of 5.3 characters ±

0.3 (SD), one for each of the four study modes. In this way, the same text was not associated with the same CVK mode .

**Outcome measures**

During the three evaluations, objective data such as text input speed (number of characters per minute) were collected, including punctuation marks and spaces. Selection errors, backspaces and correction times were not taken into account. At the D30 and D60 evaluations, satisfaction was evaluated using a 0-10 visual analogue scale (VAS). On D30, the participants were asked to classify the four modes in order of their preference.

In addition to these evaluation sessions, the CVK automatically recorded time of use of the device by the participants in their home environments outside of the evaluation sessions. The recording began as soon as the cursor of the mouse moved in the zone of the onscreen keyboard and stopped when the cursor moved out with the keyboard or was static over the onscreen keyboard. For participants who used a scanning system, the recording was stopped at the end of three runs without a selection.

**Data analysis**

To compare the effect of the four modes on text input speed, repeated-measures ANOVAs were carried out. Keyboard (static or dynamic), word prediction (yes or no) and evaluation (D0, D30, or D60) were the factors included evaluated.

**Results**

**Participants**

**Table 1:** Characteristics of participants (P: participants using a pointing device; S, participant using linear scanning)

| Participants | Age (years) | Sex | Diagnosis | Device |
|---|---|---|---|---|
| **P1** | 22 | M | Myopathy | Pointing |
| **P2** | 41 | M | Locked-in syndrome | Pointing |
| **P3** | 35 | F | Locked-in syndrome | Pointing |
| **P4** | 26 | F | Myopathy | Pointing |
| **P5** | 33 | M | Myopathy | Pointing |
| **P6** | 38 | M | Locked-in syndrome | Pointing |
| **P7** | 32 | M | Myopathy | Pointing |
| **P8** | 44 | M | Tetraplegia | Pointing |
| **P9** | 49 | M | Tetraplegia | Pointing |
| **S1** | 53 | M | Locked-in syndrome | Scanning |

10 participants, 8 males and 2 females, with a mean age of 37±10 (SD) years were included. Among them, 4 had locked-in syndrome, 4 had myopathies, and 2 had cervical spinal cord injuries.

Of the 10 participants, 5 also used their home computer for work purposes. 9 participants used a pointing device to access the computer and 1 participant used a scanning system (row-column pattern). Of the 9 participants who used pointing devices, 4 used a head-pointing device, 4 a specific type of pointer operated by the upper limb (e.g. joystick or trackball), and 1 an eye-pointer. Mean duration of use of the pointing device was 53±37 (SD) months. The habitually used on-screen keyboard was a Windows on-screen keyboard for 5 participants, a keyboard available by free download for 3 participants, and a commercially available keyboard for 2 participants (all were static AZERTY on-screen keyboards). Mean duration of on-screen keyboard use was 67±67 (SD) months. All of the participants had direct prior experience with word prediction software but not with dynamic keyboards.

**Usage time of each mode**

Table 2 shows the usage time of each mode by each participant. Mean usage time over the 2-month period was 100±105 (SD) hours. At the end of the first month (D30), 3 participants chose the static mode and 6 chose the static +word prediction mode. The remaining participant was the participant who used linear scanning, and he chose the dynamic mode. No participants chose the dynamic+word prediction mode.

Several participants did not use all four modes during the first month. One participant intensively used the static and static +word prediction modes (Table 2).

**Table 2:** Usage time in hours (and as a percentage of overall time of use of the CVK) of each mode over the 2-month study period for each participant (P: participants using a pointing device ; S: participant using linear scanning ; St: Static cvk mode ; StW: Static+Word CVK mode ; D: Dynamic CVK mode ; DW: Dynamic+Word CVK mode)

| | First Month | | | | Second Month |
|---|---|---|---|---|---|
| **Participants** | **St** | **StW** | **D** | **DW** | |
| **P1** | 0.3 (5.3%) | 3.8 (66.7%) | 0.4 (7%) | 1.2 (21%) | 2 (StW) |
| **P2** | 3.4 (11%) | 23 (74.4%) | 3.8 (12.3%) | 0.7 (2.3%) | 21.5 (StW) |
| **P3** | 15.2 (28%) | 22.1 (40.8%) | 6.4 (11.8%) | 10.5 (19.4%) | 20.5 (StW) |
| **P4** | 38.5 (78.7%) | 10 (20.5%) | 0.1 (0.2%) | 0.3 (0.6%) | 29.5 (StW) |
| **P5** | 12.3 (56.9%) | 0.6 (2.8%) | 0.1 (0.5%) | 8.6 (39.8%) | 0.7 (StW) |

| | | | | | |
|---|---|---|---|---|---|
| **P6** | 101.2 (40.8%) | 129.3 (52%) | 12.8 (5.2%) | 5.1 (2%) | 122 (St) |
| **P7** | 41.2 (74.2%) | 0.1 (0.2%) | 1.9 (3.4%) | 12.3 (22.2%) | 44.4 (St) |
| **P8** | 0.3 (0.4%) | 24.3 (29.4%) | 7.8 (9.5%) | 50 (60.7%) | 3 (StW) |
| **P9** | 11.7 (19.4%) | 48.6 (80.5%) | 0 (0%) | 0.1 (0.1%) | 20.1 (St) |
| **S1** | 0.2 (1.2%) | 1.7 (10%) | 15 (88.2%) | 0.1 (0.6%) | 8.5 (D) |

**Text input speed**

**Table 3:** Mean (SD) text input speed (characters/minute) for each evaluation.

| **CVK Modes** | **D0** | **D30** | **D60** |
|---|---|---|---|
| | **Mean (SD)** | **Mean (SD)** | **Mean (SD)** |
| **Static** | 23.4 (12.9) | 22.6 (12) | 12.7 (2.2) |
| **Static +Word** | 23 (12.3) | 21.5 (12) | 24.3 (11.3) |
| **Dynamic** | 11.9 (4.9) | 11.6 (6.5) | 5.5* |
| **Dynamic+Word** | 11.5 (6.9) | 12.9 (7.6) | N/A |

*Only S1

The optimal use of an unfamiliar on-screen keyboard may require a learning process. We performed longitudinal measurements to evaluate the effects of usage over time (Table 3). There was no significant change in text input speed across evaluation sessions ($p$=0.97) (Table 4). Neither were there any significant interactions between mode and evaluation session. Consequently, the results of the three evaluations were averaged.

**Table 4 :** ANOVA

| **Effect** | **p-value** |
|---|---|
| Time (D0 vs D30 vs D60) | 0.97 |
| Keyboard type (Static vs Dynamic) | 0.01 |
| Word prediction (With vs Without) | 0.82 |
| Keyboard type * Word prediction | 0.4 |
| Time * Word prediction | 0.55 |
| Keyboard type * Time | 0.34 |
| Time * Keyboard type * Word prediction | 0.19 |



**Effect of mode on text input speed**

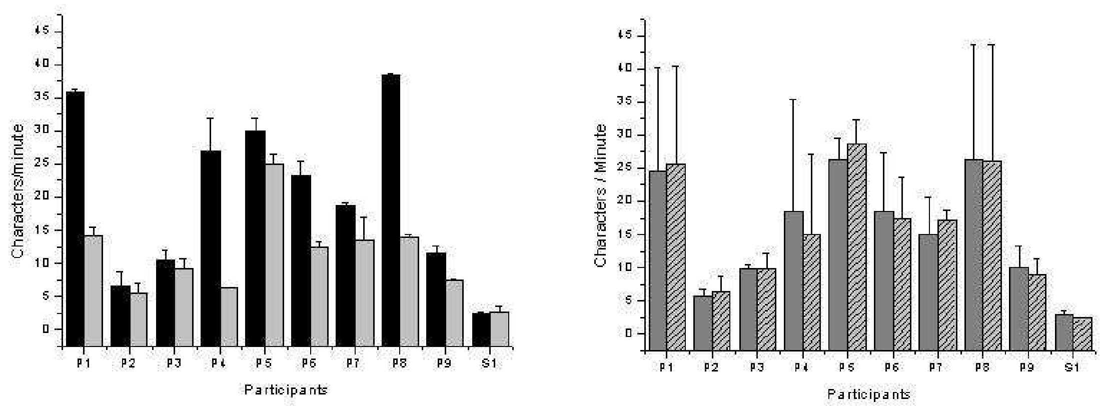


*Figure 5 : Text input speed (characters/minute) (mean (SD) of the 3 evaluation sessions for each patient) (P: participants using a pointing device; S, participant using linear scanning) static; dynamic; without word prediction; with word prediction*

256 Use of the dynamic keyboard decreased text input speed by a mean of 37%±27 (SD) compared with use of the static keyboard. This reduction was statistically significant ($p$=0.01) (Table 3). Use of word prediction had no effect on text input speed ($p$=8.2). There were no significant interactions between modes.

260 We identified no characteristics (e.g. age, sex, type of pointing device, diagnosis, usage time, or time since acquisition of the pointing device) that appeared to be related to whether the dynamic keyboard or word prediction tool increased or decreased text input speed.

264 **Participant satisfaction**

266 **Table 5:** Visual analogue scale satisfaction scores (out of 10) (P: participants using a pointing device; S, participant using linear scanning)

268 *denotes the mode chosen by each participant for the second month of the study

| | **CVK Modes** | | | |
|---|---|---|---|---|
| **Subjects** | **Static** | **Static + Word** | **Dynamic** | **Dynamic + Word** |
| **P1** | 7 | 6* | 2 | 3 |
| **P2** | 5 | 6* | 3 | 5 |
| **P3** | 2 | 5* | 2 | 0 |
| **P4** | 5 | 4* | 1 | 0 |
| **P5** | 6 | 7* | 5 | 4 |
| **P6** | 7 | 7* | 0 | 0 |
| **P7** | 9* | 8 | 4 | 4 |
| **P8** | 7 | 6* | 0 | 0 |
| **P9** | 7* | 6 | 3 | 3 |
| **S1** | 5 | 6 | 7* | 7 |

Table 5 shows the level of satisfaction of each participant on the VAS. All 9 participants who used pointing devices reported greater satisfaction with the static keyboard than with the dynamic keyboard. However, the participant who used linear scanning was more satisfied with the dynamic keyboard.

At the end of the study, 9 of the 10 participants reported that they preferred to keep their own on-screen keyboard. A single participant who used a pointing device, wanted to keep the CVK (in the static +word prediction mode) instead of the Windows XP keyboard he used previously.

**Discussion**

The primary aim of this study was to carry out a preliminary evaluation of the effect of a dynamic on-screen keyboard and the addition of a word prediction tool to a static and dynamic on-screen keyboard on text input speed. We hypothesized that both word prediction and the dynamic keyboard would increase text input speed and thus the combination of both systems would further increase text input speed, however the results showed that our hypotheses were false. The main findings were that use of the dynamic keyboard decreased text input speed compared with the static keyboard and the addition of word prediction neither increased nor decreased text input speed. Most participants preferred to return to their habitual keyboards at the end of the study.

**Dynamic versus standard keyboard**

Dynamic keyboards have existed for several years, and are particularly used by people who use scanning systems (Heckathorne [17]) (Gibler [27]) to increase text input speed and communication rate (Heckathorne [17]) (Baletsa [28]), although they were also designed for people who use pointing devices (Wandmacher [26]) (Merlin [19]) (Ward [16]). In 2009-2010, our team developed a dynamic keyboard which was intended for use by users of both scanning systems and pointing devices (Wandmacher [26]).

The results of our study, although preliminary, suggest that dynamic keyboards may be ill-suited for participants who use pointing devices. Text input speed was decreased by the dynamic keyboard compared with the static keyboard and only one participant (the participant who scanned) chose to continue using the dynamic keyboard during the second month of the trial, suggesting a lack of subjective benefit in most cases. However, our results contrast with those of Merlin and Reynal (2010) who showed that their dynamic keyboard improved text input speed by 20% compared with a static QWERTY keyboard in 6 disabled participants who used pointing systems (Merlin [19]). This difference may be explained by the fact that the type of prediction system used was different. In their system, the characters which had a low probably of being selected were replaced by those with a high probability, thus creating a repetition of these characters across the keyboard and increasing the ease with which they could be selected (Merlin [19]). In our keyboard, only the position of the character is altered according to its selection probability, requiring the subject to search for the desired character. Since the disposition of the characters cannot be learned, this may increase the cognitive load of the task (Lesher [29]).



Although there are very few studies on the effects of the design of dynamic keyboards on text input speed in disabled subjects, it is likely that the design is important. For example, the layout of static on-screen keyboards has been shown to affect text input speed in healthy and disabled subjects (Vigouroux [30]), (Raynal [31]), (Vigouroux [32]). Several studies have also shown that the keyboard layout also affects text input speed in healthy subjects using scanning systems (Lesher [29]).

Despite the fact that the dynamic keyboard had no effect on his text input speed, the single participant who used linear scanning in our study chose to keep this device during the second study month. This suggests that there was a subjective advantage of this keyboard for this participant. The subjective benefits of dynamic keyboards in have previously been described in participants with motor disability who use scanning systems (Heckarthone [17]). This advantage of the dynamic keyboard when used with scanning systems requires confirmation in larger numbers of participants who use scanning systems, such as those with amyotrophic lateral sclerosis, locked-in syndrome, and advanced multiple sclerosis.

**Effect of word prediction**

The goal of word prediction is to increase text input speed by eliminating the need to select each letter in the word. Although it has been demonstrated that word prediction reduces the number of keystrokes, at least in healthy subjects (by 10-39.6% when coupled with a dynamic keyboard and by 7.9% when coupled with a static keyboard) (Lesher [29]), the effects on text input speed are disparate. The results of our study showed that the addition of word prediction had no effect on text input speed. This result is similar to some results in the literature and contrasts with others. Closer examination of the literature suggests that the different effects of word prediction found may be related to the user population and/or the type of system it is coupled with. Studies in healthy subjects have found improvements of approximately 3 words per minute in healthy subjects using word prediction with on-screen keyboards but not with standard keyboards (Anson [22]), (Anson [33]). Word prediction did not, however, appear to be effective in healthy subjects using a scanning system (Koester [21]). Koester and Levine (Koester [23]) found that word prediction slightly improved text input speed in healthy subjects using a mouth stick on a standard computer keyboard while it significantly decreased text input speed (by a mean of 41%) in high-level tetraplegic subjects.

Other studies in disabled participants have also found negative results for the use of word prediction. A previous study by our group (Laffont [34]) which evaluated the addition of word prediction in adults with cerebral palsy who used voice synthesizers found no significant improvement for 4 out of 10 participants. In a series of studies involving individuals with spinal cord injury and persons with normal abilities, Koester (Koester [21]) (Koester [23]) found that the word prediction system reduced the number of key selections necessary, however, each selection took significantly longer to make, leading them to suggest that the cognitive costs of using a word prediction system overshadowed any potential benefit associated with the method, particularly for the patient group.

The effect of word prediction might be influenced by several parameters. Different search strategies can influence input text speed, such as the number of letters the subject types before searching the list (Koester [35]). This was not evaluated in the present study since we gave no indications to the disables participants in order to assess their spontaneous use. Further studies regarding this factor would provide useful information to therapists for training disables participants.

The number of predicted words provided is also likely to be an important factor because of the time required to scan the list. The Sybille system displays six - seven predicted words at a time. There is a trade off between the time gained as a result of keystroke savings when using word prediction and the time lost in searching a list of predicted words (Koester [35]). Following a series of studies Koester et al. (Koester [21]) (Koester [23]) suggest that each additional word in the list increases search time by 150ms. In a simulation study, Swiffin (1989) found that beyond 6 words, the list search time outweighed the keystroke savings (Swiffin [36]). However, at present, there are too little data in disabled people to determine the optimal number of words which should be displayed for such populations.

Another parameter that may influence the effect of word prediction is the position of the predicted-word list on the screen. We used two positions (above the static keyboard and left of the dynamic keyboard) and although they are typically used, we do not know what their effect on text entry speed might be. Although there are some indications in the literature that the location of the prediction list might affect the accuracy of text entry and the ease of use of word prediction (Tam [37]), (Tam [38]), the optimal position remains to be determined.

It is interesting to note that although word prediction did not improve text input speed, 7 of the 10 participants chose to continue using the word prediction mode during the second study month, suggesting that they perceived a subjective benefit. They perhaps wanted to have the possibility to use it if they wished, indeed some expressed this: “I can use it when I need to”. Some participants also expressed difficulties in looking for words in the list whilst paying attention to the keyboard, the text to be copied, the text they were writing etc. which reflects the notion of a high cognitive load.

**Patient satisfaction**

At the end of the study, 9 of the 10 participants reported that they preferred to keep their own on-screen keyboard. We suggest that the reason for this is that the dynamic keyboard perturbed most of the users since they could not learn the position of the letters. With regard to the static keyboard evaluated, the patients already used static AZERTY keyboards and were more familiar with their own. There may also be an element of resistance to change to a new device, termed path dependence. For example, Dvorak showed that the layout of the qwerty keyboard was taken from the design of early typewriters and has not changed despite arguments that other layouts may be more efficient or ergonomic (Dvorak [9])

## Limitations

This study has several limitations. The time spent by each participant on each usage mode was not equal which may have influenced the results. It is possible that with more practice on certain modes, there might have been more improvements. However, the fact that subjects chose not to use certain modes suggests that they did not find them helpful.

The word prediction dictionary (Higginbotham [39]) and texts used can also influence text input speed, however, we randomized the texts and Sybille contains a large dictionary and we thus hope that any effect was limited.

## Conclusion

In this preliminary study, the dynamic keyboard and the addition of a word prediction tool failed to improve text input speed compared to a static on-screen keyboard without word prediction in adults with functional tetraplegia who used pointing devices and scanning system.

These results highlight the importance of testing assistive systems in the participants' everyday setting to ensure that the product under development meets the needs of the future users.

Our study raises questions regarding many points, such as the best ergonomic design of a dynamic keyboard and the optimal number and position of words that should be predicted. Future studies should aim to address these questions in larger numbers of participants who use scanning systems.

## Declaration of Interest statement

None of the authors has any declaration of interest to report regarding this study.

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**Figure 1:** The CVK on-screen keyboard

**Figure 2:** Reorganization of the dynamic letter sub-keypad during input of the first two letters of the word ‘three’.

**Figure 3:** CVK dynamic on-screen keyboard with word prediction and letter prediction

**Figure 4:** The three evaluations

**Figure 5:** Text input speed (characters/minute) during a copying task (P: participants using a pointing device; S, participant using linear scanning)

static; dynamic; without word prediction; with word prediction

**Figure 6:** text input speed (characters/minute) during spontaneous text production (P: participants using a pointing device; S, participant using linear scanning). All modes were not evaluated by all participants, as some participants switched off specific modes during home use.

static; dynamic; without word prediction; with word prediction

**Figure 7:** Effect of the practice period on text input speed (characters per minute) during the copying task (P: participants using a pointing device; S : participant using linear scanning). During Evaluation 3, some participants did not use all four modes.

Evaluation 1; Evaluation 2; Evaluation 3

**Table 1:** Characteristics of participants (P: participants using a pointing device; S, participant using linear scanning)

**Table 2:** Usage time (hours) of each mode over the 2-month study period in each participant (P: participants using a pointing device; S, participant using linear scanning)

**Table 3:** Mean text input speed (characters/minute)

**Table 4:** Visual analogue scale satisfaction scores (P: participants using a pointing device; S, participant using linear scanning)

*denotes the mode chosen by the participants for the second month of the study

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People with disabilities can have difficulty using a computer and may type very slowly. We tested two systems designed to improve typing speed, based on virtual keyboards in 10 severely disabled people. Word prediction improved typing speed for 1 in 2 people. A dynamic keyboard (which predicts the next letter) may be useful for people who cannot use a pointing device but not for those who can. Further studies are needed to improve the ergonomic design of the word prediction system and to test the dynamic keyboard on more people.